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14. ABSTRACT This TOP details specific tests designed to both measure and analyze the concentrations of toxic gases and aerosols produced during equipment and systems operations such as would occur during firing of weapon systems, operation of engines during automotive operations, operation of fuel fired personnel heaters, operation of any fuel burning systems, e.g., generators and compressors, and live fire vulnerability testing..					
15. SUBJECT TERMS					
Carbon Monoxide (CO)		Sulfur Dioxide (SO ₂)		Nitrogen Dioxide (NO ₂)	
Carbon Dioxide (CO ₂)		Nitric Oxide (NO)		Lead (Pb, particulates)	
Ammonia (NH ₃)		Hydrogen Cyanide (HCN)		Fire Suppressants	
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TEST OPERATIONS PROCEDURE

Test Operations Procedure (TOP) 2-2-614
AD No.: ADA418728

31 October 2003

TOXIC HAZARDS TESTS FOR VEHICLES AND OTHER EQUIPMENT

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1. SCOPE. This TOP details specific tests designed to both measure and analyze the concentrations of toxic gases and aerosols produced during equipment and systems operations such as would occur during:

- a. Firing of weapons systems.
- b. Operation of engines during automotive operations.
- c. Operation of fuel fired personnel heaters.

*This TOP supersedes TOP 2-2-614, 28 February 1995 (DTIC AD No.: A291466).

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- d. Operation of any fuel burning systems, e.g., generators and compressors.
- e. Live fire vulnerability testing.

The emphasis of these tests are to verify compliance with Army occupational safety and health standards in accordance with AR 40-5¹ as defined in the system specific Test and/or Evaluation Plan. Occupational health and safety of test personnel should be covered by a specific job hazard analysis under the purview of the test director and responsible safety professionals.

Toxic Contaminants Covered. The toxic contaminants addressed in this document include:

- a. Carbon Monoxide (CO).
- b. Carbon Dioxide (CO₂).
- c. Ammonia (NH₃).
- d. Sulfur Dioxide (SO₂).
- e. Nitrogen Dioxide (NO₂).
- f. Nitric Oxide (NO).
- g. Acid Gases (HBr, HCl, HF, HNO₃, and H₂SO₄).
- h. Fire Suppressants.
- i. Lead (Pb, particulate).
- j. Particulates (inhalables and respirables).
- k. Hydrogen Cyanide (HCN).
- l. Formaldehyde.
- m. Acrolein.
- n. Carbonyl fluoride (COF₂).

These compounds are the most common contaminants to which soldiers and other personnel working with Army materiel may be exposed. Appendix A summarizes and discusses, individually, the physiological issues and hazards to health associated with each of the listed compounds. Appendix C lists the applicable standards for exposure to these toxic compounds.

****Superscript numbers correspond to references in Appendix F.**

In addition to the above compounds that represent a specific toxic threat to personnel, the following hazards may also be assessed:

- a. Explosive hazard.
- b. Asphyxiation (oxygen depletion).

Hydrocarbons and hydrogen gas are sometimes measured to assess the explosive hazard posed to soldiers and other personnel. In most cases hydrocarbon and hydrogen analysis will be quantified in reference to the lower explosion limit (LEL) concentration for a light straight chain alkane (methane, ethane, propane, etc.) or hydrogen concentration as determined by the proper instrumentation calibration protocol. Oxygen concentration is also measured to assess the overall threat to personnel that may be in an oxygen deprived environment.

Note: The policies and procedures specified in AR 70-25² governing the use of volunteers in Department of the Army research, wherein human subjects are deliberately exposed to unusual or potentially hazardous conditions, will apply to tests involving exposure of personnel to toxic contaminants. With rare exception requiring special approval, civilian or soldier participants in Developmental Test Command (DTC) tests will not be used as the subjects of experimentation. Additionally, because the equipment, systems, and operational environment subject to tests, as provided by this document, are military unique, they are exempt from Occupational Safety and Health Administration (OSHA) standards dealing with toxic contaminants except those mandated by the Surgeon General in Executive Order 12196³.

2. FACILITIES AND INSTRUMENTATION. Test facilities and instrumentation are unique to specific test types and toxic gas and aerosol testing is best guided by the format in which detailed test plans (DTPs) are prepared. The "Facilities and Instrumentation" details are presented in paragraph 4, (Test Process) below.

3. REQUIRED TEST CONDITIONS. These details also are presented in paragraph 4 for the reasons given in the preceding paragraph.

4. TEST PROCEDURES. This paragraph addresses five specific test types including: Automotive, Weapons Systems (Ground), Chamber, Live Fire Vulnerability, and Miscellaneous. This paragraph will include subparagraphs which are detailed under specific heading titles including: Objectives, Facilities and Instrumentation, Required Test Conditions, Criteria (Standards), Required Data, Test Methods, and Data Reduction/Presentation.

4.1 Automotive Tests.

a. These tests usually form a part of overall testing governing "Automotive Safety and Health Hazard Evaluation"⁴. Paragraph 4.7 of Reference 5 covers "Toxic Gas Measurement" and specifies that details will be presented in this TOP.

b. Automotive tests include conventional wheeled vehicles such as automobiles, trucks, multipurpose/utility vehicles (high mobility multipurpose wheeled vehicle (HMMWV)), fork lifts, earth movers, tankers, cranes, etc., which usually traverse primary and secondary roads as well as cross country terrain. Automotive testing does not include firing weapons. Weapons fire tests will be detailed in paragraph 4.2.

4.1.1 Objective. During automotive testing, the objective is to measure concentrations of toxic gases resulting from realistic automotive operations of military vehicles to determine the degree of toxic gas hazard to operating crews, maintenance crews, and vehicle occupants.

4.1.2 Facilities and Instrumentation.

a. Facilities.

- (1) Automotive test courses as specified in the DTP or as required.
- (2) Swimming and fording facilities as specified in the DTP or, as required.

b. Instrumentation. Automotive tests require instrumentation to measure concentrations of four gaseous compounds including: CO, CO₂, SO₂, and NO₂. In addition, instrumentation is needed to obtain ambient atmospheric data consisting of wind speed, wind direction, temperature and relative humidity (RH). Vehicle speed should be recorded during testing and provided to the toxic gas tester. Guidance governing the suggested permissible error and minimum detection limit for the instrumentation is provided in Appendix D. It should be noted that these are general guidelines only for usual situations; more stringent requirements may be necessary for special circumstances. Instruments measuring gas concentrations should provide output signal and data.

4.1.3 Required Test Conditions.

a. The test vehicle must be prepared and equipped to the standards required of the operational configuration or as specified in the DTP. The testing should be conducted with any auxiliary devices that affect the distribution of engine or heater exhaust, such as applique armor, fording or swimming kits, etc.

b. The engine and its supporting equipment (e.g., auxiliary power units and heaters) should be adjusted to the approved technical specifications unless otherwise directed by the test plan.

Note: Toxic gas and aerosol measurements involving fuel burning equipment can be tested under less than optimum conditions to assess a worst case toxic gas scenario. A cold engine, one which is "out of proper timing", or otherwise out of adjustment following continued field use, may provide for greater concentrations of toxic contaminants than one adhering rigorously to technical specification.

c. For vehicles where sealing prevents natural ventilation (e.g., vehicles equipped with NBC protective systems), build-up of carbon dioxide can result from normal crew/occupant(s) respiration. Special emphasis on carbon dioxide measurement should be considered for these situations.

d. The test course should be dry (no standing water) and testing should be avoided during inclement weather in that some of the toxic gases are water-soluble. This condition could potentially cause lower than expected concentrations for these particular analytes.

e. The vehicle operator and/or crew must be certified to operate the vehicle.

f. Test vehicles should be equipped with a functional and tested toxic gas alarm system or, in its absence, operating crew and occupants must be equipped with respirators to protect personnel from over exposure.

g. Data should not be collected and testing should be avoided if the interior temperature is not within the operating temperature and humidity range of the selected instrumentation.

h. Stationary testing should be avoided when the ambient RH exceeds 85 percent, wind speed exceeds 10 mph or wind gusts exceed 20 mph.

4.1.4 Criteria. Personnel shall not be exposed to concentrations of toxic substances in excess of the limits specified in either the Department of Defense (DoD) Occupational Safety and Health (OSH) standards or specialized standards applicable to military unique equipment, systems, or operations^{1,3,6,7,8,9}. In effect, the preceding statement indicates that the published Occupational Safety and Health Administration (OSHA) standards apply to both military and civilian personnel under DoD cognition with the exception of revisions/addenda approved by the Army Surgeon General (TSG) or "specialized standards applicable to military unique equipment, systems, or operations" such as the standards for exposure to carbon monoxide^{1,8,9}. Refer to Appendix C, Table C-1 for recommended toxic gas exposure limits.

4.1.5 Required Data. The specific data required for individual tests will be explicitly defined in the DTP. Typical data that may be required for testing are as follows:

a. Time-weighted average (TWA) concentrations of the toxic gases measured at the breathing zones of the crew members/occupants.

b. Vehicle interior temperature (°C).

c. Vehicle interior relative humidity (%RH).

d. Ambient temperature (°C).

- e. Vehicle identification number.
- f. Total hours on engine, total time on vehicle, and any additional pertinent information.
- g. Test duration (minutes).
- h. Vehicle speed (mph) (as applicable).
- i. Sampling probes, analyzer types, model, serial numbers, calibration dates, and manufacturer.

4.1.6 Method. The following test procedures and methods are common to "Automotive Tests."

a. A safety assessment of the vehicle will be conducted to determine: the extent of any existing toxic gas hazard, what gases may be prevalent in the vehicle, and the critical operational mode(s) that are most likely to produce significant concentrations of these gases. The findings of the safety assessment will determine the test instrumentation required and the operational conditions that are involved. If special equipment could affect exposure (i.e., fording, swimming kits, curtains, etc.), tests should be conducted with this equipment installed.

b. The vehicle configuration during toxic gas and aerosol testing will depend on both the design and expected use. An appropriate scenario should be developed, but in the absence of a specific scenario, the following procedure is recommended:

Measurement data, as specified in paragraph 4.1.5 will be collected for time periods of not less than 30 minutes under the conditions determined during the safety assessment as follows:

(1) Mobile vehicle at 0.25 and 0.5 of the vehicle's maximum speed or other speeds considered appropriate.

(2) Stationary vehicle with the engine at normal tachometer idle speed and the prevailing wind against each side of the vehicle (four conditions) or worst case scenario combination of wind and exhaust.

(2) During fording with engine idling and at vehicle speeds compatible with the fording operation.

(3) If appropriate, additional data on long-term exposures (4 to 8 hr) should be obtained during endurance testing to supplement the data obtained during the 30 minute trials.

4.1.7 Data Reduction and Presentation. The data obtained during the automotive tests will be reduced and presented as is specified in the following subparagraphs:

a. Determine the time-weighted average concentration for each gas, and the specific location of the measurement in the vehicle, in accordance with the following formula:

$$TWA_c = [c_1t_1 + c_2t_2 + c_3t_3 + \dots + c_nt_n]/T$$

where:

TWA_c = the total equivalent exposure for a single test episode of "T" (min).

t = an individual exposure period (min).

c = the measured gas concentration (e.g., ppm) for the specific exposure time period.

The subscripts represent the individual time segments (1 through n) for each test episode.

b. The TWA average will be calculated for the intervals specified in the DTP. If no specific intervals are stipulated in the DTP, Chemistry Unit personnel will present the data in a logical and appropriate format based on their experience and professional knowledge.

c. The TWA average data will be compared to the toxic exposure limits for the appropriate analytes as detailed in Appendix C.

d. A summary table of test conditions, vehicle configuration and test results, by individual trial numbers, will be included.

4.2 Weapons Systems Tests.

a. Weapons systems tests include combat vehicle systems such as tanks, personnel carriers, mobile armored systems carrying an operating crew, self-propelled howitzers, infantry fighting vehicles, etc. These systems usually involve an enclosed crew, where internal ventilation, although designed rigorously to appropriate specifications, is marginally functional particularly when rapid weapons fire results in a quick build-up of toxic gases.

b. Ground mounted weapons (towed artillery, mortars, individual weapons, rifles, pistols, etc.) and ammunition are normally tested in the vehicles from which they are fired. Toxic gas and aerosol testing in open air or externally mounted weapons are not normally conducted due to the rapid dissipation of the gases and the significant effects that even very light winds would have on the gas concentrations.

4.2.1 Objective. During weapon system testing, the objective is to measure concentrations of toxic gases resulting from simulations of realistic operations of weapons systems to determine the degree of toxic gas and aerosol hazard to operating crew, maintaining crews, and vehicle occupants.

4.2.2 Facilities and Instrumentation.

a. Facilities.

- (1) Firing ranges as required or as specified in the DTP.
- (2) Vehicle or weapons platform as required or as specified in the DTP.

b. Instrumentation.

(1) Weapon systems tests require instrumentation to measure concentrations of NH_3 , CO , CO_2 , HCN , SO_2 , NO and NO_2 . Some weapons systems, such as the Multiple Launch Rocket System, require the measurement of hydrogen chloride (HCl) in addition to the gases already mentioned. Weapon systems that use new or exotic propulsion systems (e.g., liquid propellants) may require analyses of other gases in addition to those listed above. These individual systems should be evaluated to determine potential toxic gas and aerosol threats based on the chemical constituents in the system. The instrumentation and sampling media should then be tailored to address the potential threats. Details regarding instrument specifications can be found in Appendix D.

(2) In addition to concentrations of the gases noted in the prior paragraph, instrumentation is needed to obtain ambient atmospheric data consisting of temperature, wind speed and direction, and RH.

4.2.3 Required Test Conditions.

a. Testing shall be conducted in accordance with an approved firing scenario provided by the user or developer. The scenario shall be representative of those conditions likely to be encountered in either training or combat and should specify the vehicle configuration (position of hatches, ventilator, engine status, firing rate, and number of rounds to be fired). Typical test scenarios are presented in Appendix E.

b. The test request must include minimum acceptable firing rates and the minimum number of rounds to be fired under each specific set of conditions. Firing rates provided should be realistic and reflect weapon temperature restrictions, the number of rounds carried by the system, and the tactical doctrine or training scenario. In the absence of providing a tactical (battle) or training scenario, a system specific test firing capability must be designated which is expected to meet the toxic gas and aerosol exposure criteria.

c. The system to be tested must be examined carefully in terms of the locations of air intakes, hatches, etc. relative to the weapon(s) exhaust and the operational modes of the ventilation system(s). A set of system configurations should be developed based on its characteristics and intended tactical use. Guidance should be solicited from the user or developer as necessary. The test design should encompass trials for configurations most likely to produce the greatest toxic gas and aerosol hazard that is consistent with tactical or training use.

d. If lead aerosol concentration measurements are planned, the area surrounding the firing position should be surveyed for lead contamination prior to the test start. If such contamination is found, the soil should be moistened with water during the test to prevent resuspension of lead-laden dust, which can interfere with lead concentration measurements.

e. Tests should include simulations of realistic degraded mode operations such as conditions resulting from failures or combat damage of critical system components including ventilation equipment, exhaust fans, filter systems or duct openings that are designed to provide a safe environment for the crews and/or occupants.

f. Safety and industrial hygiene personnel should ensure the protection of personnel from overexposure in the event concentrations of toxic gases exceed the allowable limits during testing.

g. Testing should be avoided when the ambient RH exceeds 85 percent or wind speed exceeds 10 mph (5 mph for hatches open) or wind gusts exceed 20 mph (10 mph for open hatches).

4.2.4 Criteria. Personnel shall not be exposed to concentrations of toxic substances in excess of the limits specified in either the Department of Defense Occupational Safety and Health OSH standards or specialized standards applicable to military unique equipment, systems, or operations^{1,3,6,7,8,9}. In effect, the preceding statement indicates that the published Occupational Safety and Health Administration (OSHA) standards apply to both military and civilian personnel under DoD cognition with the exception of revisions/addenda approved by the Army Surgeon General (TSG) or 'specialized standards applicable to military unique equipment, systems, or operations' such as the standards for exposure to carbon monoxide^{1,8,9}. Refer to Appendix B for standards and methods pertaining to carbon monoxide exposure and Appendix C, Table C-1 for recommended gas exposure limits for other toxic substances.

4.2.5 Required Data. The data required during testing is specified in the DTP. The data usually measured during testing are as follows:

a. Concentration versus time data for each gas of interest. The measurements will be made at the breathing zone of each crew member or occupant (e.g., ppm versus time).

- b. The predicted percent COHb level for each crew member or occupant as determined by the algorithm specified in Appendix B.
- c. Vehicle interior temperature ($^{\circ}\text{C}$).
- d. Vehicle interior relative humidity (%RH).
- e. Ambient temperature ($^{\circ}\text{C}$).
- f. Ambient relative humidity (%RH).
- g. Weapon elevation and direction.
- h. Number of rounds fired, firing rate and/or interval.
- i. Engine idle speed (rpm).
- j. Sampling probe(s), analyzers type, model, serial numbers, and manufacturer.

4.2.6 Method.

- a. Position the test vehicle on the firing range and mount air sampling tubes (also, sample collectors, as required) at the breathing zones of the crew members or occupants.
- b. Close hatches and turn on blowers or other auxiliary equipment in accordance with the DTP.
- c. Start sampling pumps.
- d. Begin firing scenario in accordance with the DTP.
- e. Record gas concentrations for the duration specified in the DTP. Generally, concentrations are recorded until the values reach a steady state condition (no ventilation of vehicle) or decay to prefire levels (active ventilation).
- f. Vehicle should be purged as required between trials.
- g. Repeat preceding test methods for other configurations, as required.

4.2.7 Data Reduction and Presentation. The data obtained during the Weapons Systems Tests will be reduced and presented as is specified in the following subparagraphs:

a. Determine the time-weighted average concentration for each toxic analyte except CO, and the specific location of the measurement in the vehicle, in accordance with the following formula:

$$TWA_c = [c_1t_1 + c_2t_2 + c_3t_3 \dots c_nt_n]/T$$

where:

TWA_c = the total equivalent exposure for a single test episode of "T" (min).

t = an individual exposure period (min).

c = the measured gas concentration (ppm) for the specific exposure time period.

The subscripts represent the individual time segments (1 through n) for each test episode.

b. The TWA average will be calculated for the intervals specified in the DTP. If no specific intervals are stipulated in the DTP, the toxic gas tester will present the data in a logical and appropriate format based on their experience and professional knowledge.

c. The TWA average data will be compared to the toxic exposure limits for the appropriate analytes as detailed in Appendix C.

d. Evaluation of CO toxic hazard will be performed as specified and detailed in Appendix B.

e. A summary table of test conditions, vehicle configuration and test results, by individual trial numbers, will be included.

4.3 Chamber Tests. Toxic gas and aerosol chamber tests are comparison-type tests to determine differences in the emissions of small arms (up to 30 mm) ammunition lots. The data obtained from these tests can be used to evaluate the effects of weapons or ammunition modifications, and/or firing rates on the levels of toxic gas and aerosol produced. These tests are conducted in chambers, rather than in armored combat vehicles (ACV) to provide assurance that the subtle differences in vehicle ventilation system performance or in the test conditions themselves do not impact the results of toxic gas concentrations emitted by the small arms ammunition.

4.3.1 Objective. To determine whether the test ammunition or a specific test condition provides increases in toxic gas emissions when compared with results obtained with the reference ammunition or test condition.

4.3.2 Facilities and Instrumentation.

a. Facilities. This test requires an enclosed chamber that captures and mixes the weapon exhaust products. Because the chamber volume is constant, the relative amount of each effluent gas produced during each trial can be determined by comparing the gas concentrations following thorough mixing of the ammunition effluents.

b. Instrumentation. Gas analyzers as used for the weapons firing tests

4.3.3 Required Test Conditions. Firing rates, including number of burst fires, number of rounds to be fired, etc. for each type and lot of ammunition in accordance with the DTP. Testing should be avoided when the ambient RH exceeds 85% or wind speed exceeds 10 mph.

4.3.4 Criteria.

a. The test ammunition or condition shall not develop concentrations of toxic gas that are in excess of that produced by the reference ammunition (condition).

b. Additional criteria as specified in the DTP or test request.

4.3.5 Required Data.

a. Peak, stabilized concentrations, and times for each effluent gas specified in the DTP or test request.

b. Chamber dimensional specifications, sampling probe positions in the chamber, and details of weapon mounting.

c. Atmospheric conditions inside and outside of the chamber including temperature (°C) and relative humidity.

d. Identifications: Weapon model, serial number, ammunition type, caliber, lot numbers, manufacturer.

e. Time duration of test.

f. Details of test conditions.

g. Sampling probe(s), analyzer types, model, serial numbers, and manufacturer.

h. Type of calibration gas used, manufacturer, lot number, and concentration.

i. Weapon cleaning materials and dates.

4.3.6 Method.

- a. Select a toxic gas and aerosol test chamber with size dependent upon the weapon to be tested. The weapon will be mounted such that the muzzle is external to the chamber. All openings in the chamber are sealed and a circulating fan will be used to ensure that ambient air and effluent gases in the chamber are homogeneous.
- b. The gas analyzers (e.g., CO, NH₃, SO₂, etc.) used in the trials will be operated in accordance with approved procedures.
- c. Gas sampling will be taken continuously from at least two positions within the chamber and will be analyzed for gases pertinent to the test.
- d. The desired number of replications for each lot or condition is ten, cost or weapon availability may preclude conducting ten replications. The number of replications should not be less than three.
- e. Each replication will be fired in random order to preclude unintended test bias.

Procedure as follows:

- (1) Select 1st lot or condition by random number generator.
 - (2) Select 2nd lot or condition, randomly, from remaining lots or conditions.
 - (3) Proceed as in (2) until all lots or conditions have been fired once.
 - (4) Repeat (1) through (3) for all subsequent replications.
- f. After completing a trial, the concentrations of all toxic gases will be recorded for a minimum of 5 minutes to permit complete mixing of the chamber gases prior to stopping the test and venting the chamber.
 - g. If the difference in the steady-state concentration values of any two analyzers for any gas exceeds 25 ppm or 2 percent of the full-scale range of the analyzer, whichever is smaller, the analyzer calibrations should be checked. If the calibration is correct, the variation cause should be investigated and corrected prior to continuing the test. If the calibration is incorrect, the affected gases will be recalibrated and all data obtained previously with those analyzers will be eliminated from computations of the mean steady-state gas concentration for that trial.

4.3.7 Data Reduction and Presentation.

- a. Determine the mean steady-state concentration for each toxic gas and trial by averaging the readings for all analyzers used.
- b. Calculate the sample means and standard deviations for each gas and ammunition lot (or condition).
- c. Lot to lot (or condition to condition) differences in mean steady-state gas concentrations will be evaluated using appropriate statistical analysis.
- d. Conclusions in the test report will state whether the mean concentrations of each gas produced by the test lot (or condition) significantly exceed mean concentrations produced by the reference lot (or condition).

4.4 Live Fire Vulnerability Tests.

a. Live fire vulnerability testing is performed on combat vehicles against conventional weapon threats. These tests assess the vulnerability of systems that are designed to provide protection to crew members against weapons that do not pose a nuclear, chemical, or biological threat. These threats could include, but are not limited to, gun-fired ammunition, missiles, rockets, mines, and artillery projectiles that may be statically detonated or dynamically fired. These tests may include several different scenarios or subtests that are designed to comprehensively evaluate vehicle performance. Each test, scenario, or subtest should be evaluated to ensure that all objectives related to toxic gas and aerosol measurement will be adequately addressed.

b. Many live fire vulnerability tests result in armor penetration events that can create several toxic gas and aerosol hazards. Combat vehicles are equipped with fire extinguishing systems that contain fire suppression agents. When a fire is detected, onboard systems automatically discharge the fire suppression agent. The toxic byproducts of pyrolyzed fire extinguishing agent are dependent upon the chemical composition, but can include CO, CO₂, HBr, HF, SO₂, NO, NO₂, NH₃, and HCN. Burning propellant will release NO, NO₂, CO, and CO₂. Burning plastics might produce HCl, acrolein, formaldehyde, and HCN. Comprehensive testing may also include oxygen depletion, particulate characterization and quantification, and metals analysis. Testing programs will analyze for the gases specified in the DTP, which can vary depending on the test objective.

4.4.1 Objective. Measure the concentration of toxic gas and aerosol hazards during Live Fire Vulnerability testing. These hazards are discussed in paragraph 4.4b and they include neat fire extinguishing agent, toxic byproducts of pyrolyzed fire extinguishing agent, as well as, combustion products of propellant and plastics. Testing may also include the measurement of oxygen depletion, particulates, and metal aerosols. Each test, scenario, or subtest should be evaluated to determine if any additional toxic gas and aerosol hazards should be measured.

4.4.2 Facilities and Instrumentation.

a. Facilities.

- (1) Firing ranges as required or as specified in the DTP.
- (2) Vehicle or weapons platform as required or as specified in the DTP.

b. Instrumentation. Whenever possible, continuous reading gas analyzers will be used and positioned as outlined in the DTP. If continuous reading analyzers are not available to measure a toxic gas or aerosol hazard at the expected concentration or necessary detection limit, then other analytical techniques that are determined acceptable and appropriate by qualified personnel must be employed.

4.4.3 Required Test Conditions. The required test conditions are governed by the DTP.

4.4.4 Criteria. The criteria for exposure to toxic gases and aerosols are presented in Reference 30. The criteria presented in Reference 30 are military unique incapacitation standards and do not equate to civilian exposure limits which are necessarily conservative because of their regulatory nature. The recommended exposure limits present in Appendix C do not apply to Live Fire Vulnerability Testing.

4.4.5 Data Required.

- a. Using appropriate gas analyzers or other techniques, measure and record the concentrations of the appropriate species in accordance with the locations specified in the DTP.
- b. In support of those measurements, meteorological data, as specified in paragraph 4.2.5 of this document and the DTP, should also be obtained.
- c. Sampling probe(s), analyzer types, models, serial numbers, and manufacturers.
- d. A summary of significant test information and conditions.
- e. Duration of the test.

4.4.6 Method. As indicated in paragraph 4.4a above, the method of testing should conform to the DTP. Generally, the test methods will approximate those specified in the paragraph governing (4.2.6) Weapons Systems Tests.

4.4.7 Data Reduction and Presentation.

- a. The data should be analyzed as stated in the DTP.
- b. If no guidance is provided, data should be reduced in the same manner as specified in the Weapons Systems Tests (para 4.2.7). Data should be presented in plot form as a full 15 minute concentration-time history for each toxic gas measured. Peak concentration, baseline concentrations 30 seconds prior to testing, 30 seconds, 1-, 5-, 10-, and 15-minute TWA concentrations should be provided in tabular form for each measured gas.

4.5 Miscellaneous Tests. This section is applicable to tests of miscellaneous engine-driven, fuel-burning or other equipment having the potential of creating a toxic hazard to operating, maintaining and other personnel following the completion of a safety assessment of the materiel under study. Included in this category of equipment are work shelters where operations are likely to produce toxic gases, mists, or dusts, or where out-gassing of chemicals or solvents used in construction may occur as a result of the items being exposed to high temperature or solar loads. This may also include tests for systems that pose new potential toxic gas and aerosol threats for unevaluated gaseous, liquid, and solid components and decomposition products.

4.5.1 Objective. To identify and measure concentrations of toxic gases that may result from the operation of miscellaneous materiel including engines, generators, air conditioners, shelters, repair enclosures, fuel fired burners, heaters, etc., and determine the degree of hazard to interfacing personnel.

4.5.2 Facilities and Instrumentation.

- a. Facilities:
 - (1) Test article(s) and ancillary systems as identified in the DTP or Test Request.
 - (2) Test range or emplacement where testing is to be performed as well as supporting personnel and equipment, as required to operate the range.
- b. Instrumentation:
 - (1) Calibrated, continuously operating gas analyzers and supporting subsystems (amplifiers, recorders, calibration gas, etc.) for measuring concentrations of all toxic gases expected.
 - (2) Calibrated gas sampling devices where steady state concentrations are expected.
 - (3) Temperature and pressure measuring transducers and supporting equipment.

(4) Collector devices for sampling atmospheres of carried particles, e.g., lead, dust, carbon laden particulates, etc. This could include sampling media or whole air sampling devices to collect samples for laboratory analysis. Whole air samples can be contained by SUMMA canisters, stainless steel cylinders, or gas bags. Sampling media could include tubes, filters, impingers, or other media designed to trap or collect particulates and gases.

(5) Equipment for collecting and recording meteorological data.

4.5.3 Required Test Conditions. The test conditions should duplicate realistic operational scenarios that are expected to provide conditions to produce toxic gases and particulate matter in or near the workplace of interacting personnel. Usually the DTP or Test Request will include specifications for the test conditions.

4.5.4 Criteria. The criteria for exposure to toxic gases and aerosols are stated in Appendix C of this document. Generally, the exposure criteria will depend upon the substances that are used or produced. Unless military unique criteria and/or medical bulletins issued by TSG are applicable, the criteria recommended in Appendix C should be presumed to apply.

4.5.5 Required Data. The data required are specified in the DTP. Generally, the data requirements as specified in paragraphs 4.1.5 and 4.2.5 are appropriate for these tests also. However, in addition, samples of particulates, as applicable, would be required. Finally, the test conditions, and duration of sampling periods would be tabulated.

4.5.6 Method.

a. Prior to conducting actual tests, a safety assessment of the equipment will be conducted to determine: the extent of any existing toxic gas hazard (or particulate matter), any gases or particulates that are prevalent in the emplacement of the equipment, and the critical operational mode(s) that are most likely to produce significant concentrations of these toxic compounds in occupied areas. The finding of the safety assessment will determine the test instrumentation required and the operational conditions that are involved.

b. Test methods used will basically follow the methods specified in paragraphs 4.1.6, 4.2.6, 4.3.6, and 4.4.6, as applicable for the specific test item involved.

4.5.7 Data Reduction and Presentation. Reduction and presentation of the data is dependent on the type of toxic contaminant under analysis and will generally follow the guidelines presented in the preceding paragraphs for Automotive, Weapons, Chamber, and Live Fire Vulnerability tests.

5 DATA REQUIRED. Data requirements have been specified for each type of test, individually in the preceding paragraph 4.0. Data requirements are presented in the various Appendices that follow the main body of this document. Appendix C includes the air quality standards for comparative and/or evaluation purposes.

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6. DATA PRESENTATION. Paragraph 4 presents the requirements for presentation of data for each of the type tests that are performed and covered by this document. In addition, details for how data are presented and the evaluative procedure for exposure to CO are given in Appendix B.

APPENDIX A. CONTAMINANTS SUMMARY

CONTAMINANTS (TOXIC HAZARDS) SUMMARY

1. BACKGROUND.

1.1 The ingestion of toxic contaminants by operators and maintainers of Army materiel systems, in addition to having the potential of affecting their health and safety, can have degrading effects upon human performance, even when health and safety issues are not involved. The surreptitious nature of the buildup of exposure levels in and around the systems underscores the need, to the fullest extent possible, for detecting, measuring, and eliminating these hazards. The critical issue that is addressed in this TOP is the potential of overexposure of soldiers to: carbon monoxide (CO), carbon dioxide (CO₂), ammonia (NH₃), sulfur dioxide (SO₂), oxides of nitrogen (NO_x), lead (Pb) aerosol, hydrogen chloride (HCl), the halons (1301, 1211, and 2402) and any other noxious compound/substance identified as either being hazardous to health and safety or contributing to degraded human performance. Exposures for some of these compounds are likely to be intense and above the present federal standards for occupational exposure¹⁸. Appendixes B and C, of this document, present the standards for all of the toxic compounds addressed in this document.

1.2 While exposure to emissions from ammunition propellants may be encountered by soldiers in a variety of operational settings, the U.S. Army's concern about the potential for the deleterious effect(s) of various air pollutants has focused on those exposures found in armored combat vehicle systems. Armored vehicle crews are particularly vulnerable to the adverse effects of exposure to the toxicants in question¹⁸ because of the closely confined space that typify the design of armored vehicle interiors and the accompanying potential for poor ventilation, particularly when operating in a closed hatch mode. Brief discussions of each of the aforementioned compounds follow in a later paragraph.

1.3 Federal occupational exposure standards⁶ for toxic compounds are based on threshold limit values (TLV) recommended in 1968 by the American Conference of Government Industrial Hygienists (ACGIH). The Federal occupational exposure standards (OSHA and ACGIH) are formally adopted by the U.S. Army in AR 40-5¹. There are circumstances for which military unique standards are developed and implemented. This is accomplished through the mechanism of the "Department of Defense (DoD) Occupational Safety and Health Program" (DoD 6055.1)⁷. TLVs are usually specified in terms of 8-hour time-weighted averages (TWA), occasionally as ceiling values (C), and are general guideline specifications. The National Institute of Occupational Safety and Health (NIOSH) recommend occupational standards for selected agents, specifically for the Occupational Safety and Health Administration (OSHA). In addition, the ACGIH also recommends "short term exposure limits" (STEL) which are time-weighted averages for 15-minute exposures. If instantaneous real-time instrumentation is monitoring an area, the STEL should be used to determine a ceiling exposure concentration (see app C for additional details). In addition to these publications the U.S. Army Center for Health Promotion

and Preventive Medicine (CHPPM) has also published guidelines for exposure to many toxic gases in the May 1999 version of the "Short-Term Chemical Exposure Guidelines for Deployed Military Personnel"¹³.

2. CARBON MONOXIDE (CO). Carbon Monoxide is particularly dangerous in that, aside from its toxicity, it is odorless, colorless and tasteless and is not ordinarily detectable by the human senses. This gaseous compound is undoubtedly one of the most dangerous and common industrial exposure hazards. The U.S. Army is concerned with the effects of CO exposure on personnel in the field when operating items of equipment or firing weapons from enclosed armored vehicles (e.g., tanks and armored personnel carriers). Additionally, even if particular CO exposures are not categorized as safety or health hazards, such exposures can degrade human performance and adversely impact system effectiveness.

2.1 Standards. The Walter Reed Army Institute for Research (WRAIR) has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. Paragraph 5.13.7.4.2 of MIL-STD-1472D⁹ specifies the exposure standards for CO in terms of the permissible carboxyhemoglobin (COHb) blood levels for personnel in aviation systems and all other systems separately. The prediction of COHb blood level for individual exposures is made by a mathematical model which is a revised form of the Coburn-Forster-Kane (CFK) equation¹⁹ given in the handbook⁸ and reprinted in Appendix B for convenience. This empirically derived equation predicts the percent COHb blood level of personnel exposed to CO through knowledge of the CO exposure level, its duration, and the work-stress level (ventilation rate) of exposed individuals. Accordingly, the equation is a useful tool for evaluating the toxic hazard associated with exposure to CO²⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

2.2 Health Effects. CO exposure results in impaired oxygen transport by the blood, thus resulting in hypoxia. Normally, oxygen from the lungs is carried through the body by the blood's hemoglobin (Hb). CO has an affinity for blood Hb, which can reduce the oxygen carrying capacity of the blood to the degree that the exposed human suffocates. The affinity of CO for Hb can be as much as 300 times greater than that of oxygen. The elimination of CO is solely through the lungs and is similar, in many ways, to absorption. The rate at which CO is eliminated from the blood is an exponential and relatively slow delay, and is a function of many physiological variables. The half-life of CO in the blood can be as much as 4 hours for healthy people at rest in an environment free of contaminants (see para 5.4.7.5 of MIL-HDBK-759B8 and app B for algorithm). Reference 10 contains data relating to the efficacy of the algorithm used for evaluating CO exposure.

3. CARBON DIOXIDE (CO₂). Carbon Dioxide is one of the products of fossil fuel burning in internal combustion engines, including the diesel engine. CO₂ is considered to be a noxious gas in that, like CO, it is colorless and odorless.

3.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

3.2 Health Effects. Where an unusually large exposure is involved, CO₂ can lead to unexpected suffocation. Fortunately, the hazard posed by CO₂ emissions (compared to CO) are rather minimal when either firing weapons or operating combat/automotive systems. One must be alert to the potential of CO₂ intoxication for combat vehicle operations in closed hatch mode without adequate ventilation, as might occur during silent watch. The closed hatch mode can cause a build-up of CO₂ in the confines of the vehicle and levels can exceed 5 to 7.5 percent concentrations. It is expected that soldier performance might degrade below acceptable limits when these high concentrations are reached.

4. Ammonia results from the combustion of propellants and other nitrogen containing substances. Exposure of soldiers to combustion emissions may occur during either training or battle with the various fielded weapons systems. Armored vehicle crews may be particularly vulnerable to exposure because of the confined crew space inside the vehicles; and the proximity of personnel to the emission source.

4.1 Standards. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

4.2 Health Effects. Exposure to ammonia gas primarily affects ones eyes and the respiratory tract. The irritant effects are immediate at exposure onset, primarily concentration dependent, and probably completely reversible at concentrations of 500 ppm and below, except possibly under conditions of prolonged exposure. Between concentrations of 50 to 100 ppm, most personnel will experience moderate eye, nose and throat irritation. The degree of discomfort should normally not degrade task performance unless eye discrimination is critical. Mostly, the irritant effect from the military viewpoint is the lacrimation (tearing) that will occur in approximately 50 percent of the personnel exposed to concentrations of about 130 ppm¹⁸.

5. SULFUR DIOXIDE (SO₂). Sulfur Dioxide is a pungent, irritating gas that is produced by the combustion of elemental sulfur or compounds containing sulfur.

5.1 Standards. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

5.2 Health Effects. Human exposure to concentrations of 1 to 50 ppm for 5 to 15 minutes may cause irritation of the eyes, nose, and throat, nasal discharge, choking, coughing, and reflex constriction of the airways. Approximately 10 to 20 percent of the healthy young adult population is estimated to be hypersensitive to the effects of SO₂.

6. **OXIDES OF NITROGEN (NO_x).** Oxides of nitrogen are a product of the combustion of propellants associated with weapons firing. The primary concern is with the production of both nitric oxide (NO) and nitrogen dioxide (NO_2). These compounds are also produced at low levels in internal combustion engines.

6.1 Standards. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards. The CHPPM recommended limits for NO_x are based on tolerance of a single exposure without encountering adverse health effects but not necessarily without acute discomfort.

6.2 Health Effects. NO has been reported to cause narcosis in laboratory animals exposed to concentrations greater than 2500 ppm. By itself, it has no irritant properties, but is frequently oxidized in air to form NO_2 . At concentrations below 50 ppm, the conversion of NO to NO_2 is slow. NO is much more toxic than NO_2 , and may cause severe irritation of the eyes, skin and respiratory tract. Short duration exposures to more than 5 ppm may result in coughing and shortness of breath. Exposures of 50 to 100 ppm can result in severe pulmonary edema, chronic airway damage, and death.

7. **HYDROGEN CHLORIDE (HCl).** The major source of HCl emissions for Army personnel results from the burning of plastics (particularly polyvinyl chloride). HCl is also released in enormous quantities during the firing of some rocket and missile engines. HCl is a major product when firing explosives containing chlorine. The firing of the hand-held Stinger missiles releases large amounts of HCl. The Multiple Launched Rocket System (MLRS) is yet another source for exposure of personnel to HCl.

7.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

7.2 Inhalation of HCl at irritating concentrations can result in coughing, pain, inflation, edema, and desquamation (scaling/peeling) in the upper respiratory tract. Acute irritations can bring about larynx and bronchi constriction, and breath holding. HCl is a strong irritant that affects the conjunctiva and the mucous membranes of the respiratory tract. Because of its solubility in water, the major effects of acute exposure of the respiratory system are usually limited to the upper passages and are severe enough to encourage prompt voluntary withdrawal from a contaminated atmosphere. The area most affected on humans is the surface components of the upper respiratory tract where it is retained or deposited unless the exposure is so concentrated that it overwhelms the scrubbing capacity of the tract.

8. FIRE SUPPRESSANTS. The U.S. Army has traditionally used Halon 1301 or other Halon derivatives as fire suppressants in both occupied and unoccupied crew space. Halons have been identified as ozone depleting chemicals (ODCs) and the U.S. government has joined an international treaty to eliminate the production and use of ODCs. The U.S. Army consequently initiated a Halon replacement research program to identify the best alternative fire suppressants. This program identified heptafluoropropane (FM-200) as the best alternative for occupied crew space and pentafluoroethane (FE-25) as the best alternative for unoccupied crew space. The U.S. Army has currently adopted the National Fire Protection Association toxicity standards for FM-200 and FE-25. Further guidance should be provided in future updates to Reference 30.

Halon 1301 and other Halon derivatives - (CBrF_3 and other chemical analogs). Agent concentrations of 5 to 6 percent by volume are considered adequate to extinguish fires of most combustible materials and this agent is the most thermally stable of the halogenated extinguishing agents. However, at temperatures above 810°K (1000°F), the agent decomposes into irritating and potentially toxic by-products, which can cause respiratory tract, skin, and eye irritations at elevated concentrations. Although Halon 1301 is the most common Halon used as a fire extinguishing agent, other Halon derivatives, such as 1211 and 2402, also may be used. The use of Halons as fire extinguishing agents by the U.S. Army will be gradually eliminated.

8.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for Halon 1301³⁰. When considering an occupational hazard or steady state concentrations see Appendix C for details on applicable standards. Furthermore, References 27, 28, and 29 also provide exposure guidelines for Halons.

8.2 Health Effects. Halon 1301 can enter the body in three different ways to provide the potential of a toxic threat by ingestion, inhalation, or absorption through the skin. For Army civilians and soldiers alike, the primary route of entry, for a gaseous compound such as Halon, is inhalation. The principal toxic effect of Halon is upon the central nervous system (CNS) and its profound irritating influence following its decomposition at temperatures greater than approximately 810°K (1000°F) on the respiratory tract, skin and eyes. Halons also function as simple asphyxiates that will displace oxygen and reduce the amount of oxygen available for respiration. It should be noted that decomposed products of Halon such as carbonyl fluoride (COF_2), hydrofluoric acid (HF) and hydrobromic acid (HBr) could result from fires associated with thermoelectric heaters. Other Halon derivatives, such as 1211 and 2402, that may be encountered will have similar health effects. FM-200 and FE-25 are cardiac sensitizers that can cause heart arrhythmia and potential cardiac arrest at extremely high concentrations.

9. **LEAD AEROSOL/PARTICULATES (Pb).** Lead is found naturally in the earth's crust, and in the atmosphere and hydrosphere. It has been used for thousands of years because of its availability and desirable properties. Ammunition (shells, projectiles, etc.) have been made of alloys of lead ever since ammunition has been in existence. Also, it is used as a decoppering agent to remove rotating band deposits from the bores of weapons. In the earliest days of its use, lead was recognized as a health hazard, both as an elemental metal and bonded in compound form. Lead can enter the body by inhalation or ingestion. Absorption of excessive amounts of lead causes diseases of the kidneys and of the peripheral and central nervous systems²². The potential of occupational exposure to lead and its compounds occurs in over 100 industrial occupations in addition to exposures of military personnel during the firing of weapons.

9.1 Standards. The standards for exposure to lead are presented in paragraph 1.2 of Appendix C. In addition to the OSHA and AGGIH criteria, permissible limits for intermittent exposures as it relates to firing ranges are presented in that appendix.

9.2 Health Effects. The adverse effects associated with exposure to lead range from acute to relatively mild. Reversible stages include inhibition of enzyme activity, reduction in motor-nerve conduction velocity, behavioral changes, and mild central nervous system symptoms. Irreversible damage causes chronic disease and death. The symptoms of severe lead intoxication include loss of appetite, metallic taste, constipation, nausea, pallor, excessive tiredness, weakness, insomnia, headache, nervous irritability, muscle and joint pains, fine tremors, numbness, dizziness, hyperactivity, and colic²².

10. **HYDROGEN CYANIDE (HCN).** HCN is classified as a general poison and it can be used as a chemical warfare agent. HCN is produced in gaseous form during ammunition propellant combustion and decomposition. The gas, which has a sweet, almond-like odor is inhaled and also absorbed through the skin. Exposure to HCN can occur in ambient air around firing ranges and in armored combat vehicles. This toxic gas is considered very dangerous and can be fatal at relatively low concentrations over long durations.

10.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

10.2 Health Effects. HCN has a high toxicity and in sufficient concentration it rapidly leads to death. HCN is considered among the list of current chemical warfare agents used by "Third World" and "Rogue" nations. The most important toxic effect of HCN is inhibition of metal containing enzymes, particularly cytochromoxidase. This enzyme is utilized for oxygen transport during cell respiration. The inhibition of this enzyme results in weakness, headache, confusion, nausea, vomiting, and increased respiration rate. The target organs include the central nervous system, cardiovascular system, thyroid, and blood.

11. **HYDROGEN FLUORIDE (HF).** HF has an immediate effect as a severe irritant and delayed or long-term effects include cardiac arrhythmia, as well as, bone deposits. HF is produced in significant quantities during fluorine containing fire suppressant decomposition. Carbonyl fluoride rapidly hydrolyzes to form HF. HF is used in its gaseous form for many industrial processes including glass etching, silicon wafer etching, and CFC production.

11.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

11.2 Health Effects. The irritating effects of HF are felt immediately in the eyes, nose, and throat. These effects are followed by ulcerative tracheobronchitis when exposed to high concentrations. Significant exposures can cause hypocalcemia and hypomagnesemia that may result in cardiac arrest and/or death. Long-term acute effects also include increased bone density caused by fluoride deposits (fluorosis/osteosclerosis).

12. **CARBONYL FLUORIDE (COF₂).** COF₂ is also produced in the decomposition of fire suppressants and other fluorine containing compounds. It quickly hydrolyzes to HF in the presence of water vapor, which is plentiful during combustion processes.

12.1 Standards. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

12.2 Health Effects. The health effects of COF₂ are very similar to HF; in that, it is a severe irritant to the mucous membranes, causes fluorosis and cardiac arrhythmia.

13. **FORMALDEHYDE (HCOH).** Formaldehyde is the simplest molecule within the aldehyde family of chemicals. This reactive compound can be formed from any type of combustion process. Formaldehyde is a colorless gas that has a pungent, suffocating odor and its odor can be detected by humans at concentrations less than 1 ppm. It is also considered carcinogenic.

13.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

13.2 Health Effects. Formaldehyde is a severe irritant to the respiratory system and mucous membranes. Exposure may be followed by cough and bronchial spasms. Exposure studies have resulted in cancer in laboratory animals; therefore, formaldehyde is considered a carcinogen.

14. ACROLEIN (2-PROPENAL, C_3H_4O). Acrolein is an aldehyde compound that can be produced in the combustion of some plastics. This compound should be considered as a potential analyte when evaluating projects that could produce fires or extreme heat in the vicinity of plastics.

14.1 Standards. The WRAIR has military specific standards that can be applied to evaluate Live Fire Testing incapacitation for this compound³⁰. When considering an occupational hazard or steady state concentrations, see Appendix C for details on applicable standards.

14.2 Health Effects. Acrolein is very irritating to the mucus membrane surfaces and it causes delayed pulmonary toxicity similar to NO_2 .

15. HYDROCARBONS. This is a general term that is intended to refer to typical light, low molecular weight, hydrocarbons such as methane, ethane, propane, acetylene, etc. These compounds are typically colorless, but may have an odor associated with them. Bottled forms of these gases many times have odor producing additives that assist in human detection.

15.1 Standards. Most hydrocarbons are listed as simple asphyxiates with no specific standard or limitation for health effects. The lower explosive limit (LEL) standard is many times used to assess an explosion hazard. The LEL is the limit of flammability or explosivity of a gas or vapor at ordinary ambient temperatures expressed in percent of the gas vapor in air by volume. The LEL concentration does not necessary represent a toxic gas hazard, but rather represents a concentration that could ignite or explode with an available ignition source. OSHA considers concentrations in excess of 10 percent of the LEL to be a hazardous atmosphere in confined spaces.

15.2 Health Effects. These gases act as simple asphyxiants without other significant physiological effects. A standard TLV is not recommended since the limiting factor is available oxygen.

16. OXYGEN. There are several potential causes for oxygen depletion from a given atmosphere of air. Oxygen is quickly consumed by combustion reactions and oxygen can be displaced from air due to high concentrations of simple asphyxiants like carbon dioxide, methane, or nitrogen. Low oxygen concentrations can cause respiratory issues, while high concentrations of oxygen can cause explosive hazards. High oxygen concentrations in air usually require a higher oxygen concentration emission source in the area.

16.1 Standards. Air normally contains 20.9 percent oxygen. The general target concentration for oxygen is between 19.5 and 23.5 percent in air. Concentrations above 23.5 percent can represent an explosion hazard. Concentrations below 19.5 percent can cause detrimental health effects. Oxygen levels lower than 12 percent are considered extremely dangerous and testing should be aborted unless personnel are supplied bottled air.

16.2 Health Effects. The health effects of oxygen depletion are summarized in Table A-1.

TABLE A-1. HEALTH EFFECTS OF OXYGEN DEPLETION

Percent Oxygen in Air	Symptoms
Less than 19.5	Respiration volume increases, muscular coordination diminishes, attention and clear-thinking require more effort.
12 to 19.5	Shortness of breath, headache, dizziness, quickened pulse, efforts fatigue quickly, muscular coordination for skilled movements lost.
10 to 12	Nausea and vomiting, exertion impossible, paralysis of motion.
6 to 10	Collapse and unconsciousness occurs.
6 or below	Death in 6 to 8 minutes.

APPENDIX B. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD

1. BACKGROUND.

1.1 Just as might occur in the industrial environment, the Army is particularly concerned with personnel exposure to carbon monoxide in that such exposure, in addition to potentially affecting health and safety, can result in performance degradation for the concerned population. Military exposure to CO is usually transient, high level exposure, which is typical during weapons firing scenarios, while exposure in the civilian community is generally one that is relatively low level and essentially steady state for long periods of time (small variation about the mean concentration).

1.2 Prior to 1980, the Army essentially evaluated soldier exposure to CO using the civilian (OSHA) standards⁶ and MIL-STD-80017 (now obsolete) for dealing with steady state and transient type exposures respectively. As is discussed in Steinberg and Nielsen²³, the civilian standards were considered too stringent for Army personnel who, fundamentally, represent a population of young, healthy soldiers in contrast to the general civilian which may vary in age and have potential associated health problems. Accordingly, the Army was in need of both adopting appropriate standards and an evaluative procedure that was acceptable to the Army Surgeon General and could be applied simply and effectively. In essence, the standard would be categorized as military unique⁷. Such a standard was adopted in May 1981 and published in MIL-STD-14729 (see para 5.13.7.4.2 Carbon Monoxide). The evaluative procedure is specified in MIL-HDBK-7598 (see para 5.4.7.5 Evaluation of Carbon Monoxide Toxic Hazard) and was published initially in June 1981.

1.3 The standard is specified in terms of permissible percentage carboxyhemoglobin (COHb) levels in the blood. A 5 percent COHb level is stated as "all system design objectives and aviation system performance limits." A 10 percent COHb limit is specified for "all other systems performance limits." The percentage COHb blood level is predicted by use of a revised form of an empirical equation (given later) developed by researchers Coburn, Forster, and Kane. This equation estimates the percentage COHb levels in one's blood based upon a measured CO exposure level, the time duration of the exposure, and the physical stress level of the exposed individual over the exposure duration. Before presenting the details of the evaluation procedure, a brief explanation of the standard should be helpful.

1.3.1 The TWA method of evaluating CO exposure with the previously existing standards was unrealistic for the military environment because it neglected to account for the actual uptake of CO by the exposed person. Specifically, the standard did not factor in the work effort on the affected personnel during the time of the exposure. Additionally, the possibility of repetitive transient exposures is not accounted for properly using the TWA method of evaluation. Transient exposures might be encountered in such as cases when firing or loading the main weapon of a tank, or trying to fly "nap-of-the-earth" missions with a helicopter.

In these examples, individual performance is a critical issue that the TWA method of evaluation did not consider. The COHb standard accounts for required performance by the individual which is precisely the reason that a 5 percent COHB level standard was selected for the aviation community as opposed to the 10 percent COHB level standard chosen for all other systems. Visual acuity is considered more critical for the airman than for the combat vehicle crewman, which accounts for the differences in the standard (5 versus 10 percent).

1.3.2 Empirical Equation. The following is extracted from MIL-HDBK-759B for convenience to the user:

$$\% \text{ COHb}_t = \% \text{ COHb}_0 [e^{(-t/A)}] + 218 [1 - e^{(-t/A)}] [1/B + \text{ppm CO}/1403]$$

where:

- % COHb_t = the predicted carboxyhemoglobin in the exposed subject.
- % COHb₀ = the amount of COHb found in nonsmoking adults.
- t = the duration of exposure in minutes.
- ppm CO = the carbon monoxide exposure in PPM of contaminated atmosphere.
- e = the mathematical constant 2.7182818 (base of natural logarithm).
- A and B = constants which are obtained from Table B-1. Both constants are dependent on the estimated activity level of the individual during the actual exposure. For combat vehicle crewpersons, the work effort level to be substituted in the equation is specified. These required levels are 4 and 3 for weapons fire and intermediate mission episodes respectively. These constants account for the minute respiratory volume of contaminated atmosphere actually respired by an exposed individual.

TABLE B-1. CONSTANTS FOR EMPIRICAL EQUATION USED TO PREDICT COHB BLOOD CONTENT

Work Effort Scale	Work Effort Description	A Value	B Value
1	Sedentary	425	806
2		241	1421
3	Light work	175	1958
4		134	2553
5	Heavy work	109	3144

The equation is popularly known as the Coburn-Forster-Kane Equation (CFKE). In its present modified form, extracted from the publication "Occupational Exposure to Carbon Monoxide"²⁴, the CFKE is adaptable easily to desk top computation and, because of its simplistic form, can also be programmed for use with a hand calculator. The user should note that the modified CFKE, in addition to accounting for the actual minute respiratory volume of contaminated air respired by the subject, also accounts for the elimination of CO by the body. It should be noted that the CFKE is fundamentally based upon laboratory experimentation and that verification of the equation should be based on actual field tests. One such test²⁰ was completed during June/July 1985 and published in 1986. The findings indicated that the CFKE, as currently used, was a reasonable predictor of COHb blood level.

2. EVALUATIVE PROGRAMS.

2.1 Standard Use of CFKE. The CFKE is best adaptable to exposure data gathered on the basis of conducting realistic operational scenarios for the particular weapon system or combat vehicle being evaluated. Such operations might include a projected 24hour, 48 hour, or other battle or training scenario. If the Training and Doctrine Command (TRADOC) provides the materiel developer with such a scenario, the data gathered during the scenario can be used directly with the computer model described by Steinberg²⁵ to determine the degree of compliance with the standard. Basically, the input data to the program consists of CO exposure segments gathered during the scenario simulation. If, for example, a group of segments is comprised of: 3 minute main weapon firing, 2 minute co-axial weapon firing, 4 minute M85 machinegun firing, 15 minute rest period, a replication of the prior firing scenario followed by a 30 minute silent watch, these exposure data are separated into eight separate segments with six of these segments (firing data) being comprised of transient data (work effort level 4) and the two intermediate periods comprised of steady state data (work effort level 3). These data would be input to the CFKE chronologically and the output would be as given on page 12 of Reference 25 (21 chronological segments). It should be noted that the data of the intermediate segments could be either estimated or measured depending on the specifications contained in the DTP or what logic would dictate. The results (COHb_t for each segment and crew position) could be plotted as a function of time to determine the extent of compliance with the standard and to indicate the critical crew position for the mission. In the event of noncompliance with the standard, the plotted results could provide the designer and/or combat developer with valuable information as to the potential for design correction or combat doctrine revision. Additionally, the risk of noncompliance with the standard can be addressed easily. In the event compliance with large margins are indicated from the plotted data, doctrine can possibly be altered or battle scenarios revised such that combat effectiveness is improved.

2.2 RATES Computer Program. This program is used by ATC to compute (predict) COHb blood concentrations from CO exposure data gathered during testing for toxic gases. Because approved toxic gas and aerosol test scenarios are not generally available in terms of many

developmental systems, and no system specific criteria (i.e., actual number of rounds required to be fired safely within a specified time period under mission specific operating conditions) exists, the RATES program examines the boundary conditions for safe operation which are (for this analysis) defined as follows:

a. Nonfiring. This is a degenerative condition in that no firing of weaponry takes place. Accordingly, no exposure to weapon induced CO will occur and this condition can continue indefinitely without hazard to the crew with the additional proviso that background CO levels are not unusually high (<35 ppm).

b. Maximum Firing Rate. This is a worst case condition in that it assumes additional replications of a given scenario are fired consecutively. The Maximum Allowable Consecutive Episodes (MACE) is defined as the maximum number of consecutive replications of a test scenario that may be fired at the maximum firing rate without exceeding the standard's allowable limit of 10 percent COHb blood level in accordance with Reference 9, paragraph 5.13.7.4.2.

c. Sustained Firing Rate (SFR). Assuming MACE has been reached; the sustained firing rate is that which is highest for any weapon of the system without exceeding the 10 percent COHb limit for any crew member or occupant. If the CO levels are high (35 to 50 ppm) a nonfiring period of sufficient duration must be determined such that COHb levels decay sufficiently to permit additional firings of weapons without exceeding the 10 percent COHb limit. If CO levels are relatively low (<35 ppm), a nonfiring period would not be required and the sustained firing rate coincides with the maximum firing rate.

2.2.1 Obviously, the maximum firing rate is the upper boundary in that the system is constrained (by design and performance) to a specific maximum firing rate. Provided the COHb level does not exceed 10 percent when firing at the maximum rate, there would be no firing restrictions. If MACE is reached, periods of nonfire must be observed such that the crew COHb levels decay sufficiently prior to permitting additional weapons firing. In this scenario the boundary conditions are MACE and SFR. A MACE, which is equivalent to several times the system's combat load, is of no practical use since the available ammunition will have been expended before reaching MACE. However, MACE does provide for a basis of comparing CO exposures among test scenarios which involve different conditions, ammunition types, numbers of rounds fired, etc. which provides the systems analyst with the means for improving combat effectiveness just as was discussed above in paragraph 2.1 for the standard use of the CFKE.

2.2.2 The firing rates discussed above do not consider temperature related firing restrictions, which may impose greater constraints upon firing than those imposed by toxic gases and aerosols. Discussion of a temperature related constraint and others is beyond the scope of this document and is mentioned to apprise the analyst that, when considering additional revisions to the model, adjustments should be made for such items as temperature, blast overpressure, and other system specific constraints. If such considerations are made, firing rate restrictions stated in system safety releases are coherent and coordinated.

APPENDIX C. STANDARDS FOR AIR QUALITY AND EXPOSURE

1. INTRODUCTION.

1.1 This Appendix is intended to provide the toxic gas and aerosol tester and/or evaluator with a complete reference list of governing air quality standards and criteria used by the U.S. Army for identifying health, safety, and performance hazards resulting from human exposure to the toxicant concentrations which are measured during tests within the scope of this document. Also contained herein is a comprehensive listing of standards and criteria, as well as, references as are applicable to each of the gases for which measurements are made.

1.2 The standards/exposure criteria applicable to toxic gas and aerosol testing by the U.S. Army are basically governed by the Federal Code⁶ and DoD instruction⁷. The Army Surgeon General (TSG) likewise can specify alternative standards, where warranted, in place of the Federal Code where special considerations must be applied, due, in part, to the character of the military exposure environment which can differ materially from exposures experienced by other populations. For example, the transient nature of some military exposures, when combined with the uncertainties of the synergistic effects of simultaneous exposure to several gases can provide for an entirely different criteria than specified in the Federal Code.⁶ There are three recognized sources for toxic contaminant standards. These include Occupational Safety and Health Administrations (OSHA), National Institute for Occupational Safety and Health (NIOSH), and the American Conference of Governmental Industrial Hygienists (ACGIH). The most stringent standard (most conservative approach) is recommended as exposure criteria in Table C-1. It should be noted that the exposure criteria presented in Table C-1 are published annually and are occasionally altered based on the most current information. These values should be checked and accordingly updated on an annual basis. Finally, there is the category of standards/criteria that are unique to the military environment, such as the standard for exposure to carbon monoxide.^{7, 8, App B.} Accordingly, all these criteria will be discussed in the following paragraphs.

2. TOXIC GAS EXPOSURE CRITERIA. This paragraph addresses the applicable standards/exposure criteria for toxic gases including carbon monoxide (CO), carbon dioxide (CO₂), ammonia (NH₃), sulfur dioxide (SO₂), oxides of nitrogen (NO_x), hydrogen chloride (HCl), bromotrifluoromethane (Halon) (CBrF₃), hydrogen cyanide (HCN), hydrogen fluoride (HF), carbonyl fluoride (COF₂), formaldehyde (HCOH), and lead aerosols/particulates.

TABLE C-1. APPLICABLE EXPOSURE CRITERIA^{6,26}

Compound	Exposure Type	OSHA	NIOSH	ACGIH	Recommended Exposure Limits
Acrolein (C ₃ H ₄ O)	TWA	0.1	0.1	0.1	0.1
	STEL	NA	0.8	NA	0.8
	Ceiling	NA	NA	NA	NA
	IDLH	NA	2	NA	2
Ammonia (NH ₃)	TWA	50	25	25	25
	STEL	NA	35	35	35
	Ceiling	NA	NA	NA	NA
	IDLH	NA	300	NA	300
Carbon Dioxide (CO ₂)	TWA	5000	5000	5000	5000
	STEL	NA	30000	30000	30000
	Ceiling	NA	NA	NA	NA
	IDLH	NA	40000	NA	40000
Carbon Monoxide (CO)	TWA	50	35	25	25
	STEL	NA	NA	NA	NA
	Ceiling	NA	200	NA	200
	IDLH	NA	1200	NA	1200
Carbonyl Fluoride (COF ₂)	TWA	NA	2	2	2
	STEL	NA	5	5	5
	Ceiling	NA	NA	NA	NA
	IDLH	NA	NA	NA	NA
Formaldehyde (HCOH)	TWA	0.75	0.016	NA	0.016
	STEL	2	NA	NA	NA
	Ceiling	NA	0.1	0.3	0.1
	IDLH	NA	20	NA	20
Hydrogen Chloride (HCl)	TWA	NA	NA	NA	NA
	STEL	NA	NA	NA	NA
	Ceiling	5	5	5	5
	IDLH	NA	50	NA	50
Hydrogen Cyanide (HCN)	TWA	10	NA	NA	NA
	STEL	NA	4.7	NA	4.7
	Ceiling	NA	NA	10	10
	IDLH	NA	50	NA	50
Hydrogen Fluoride (HF)	TWA	3	3	NA	NA
	STEL	NA	NA	NA	NA
	Ceiling	NA	6	3	3
	IDLH	NA	30	NA	30

See footnote and notes at end of table.

TABLE 2-1 (CONT'D)

Compound	Exposure Type	OSHA	NIOSH	ACGIH	Recommended Exposure Limits
Nitric Oxide (NO)	TWA	25	25	25	25
	STEL	NA	NA	NA	NA
	Ceiling	NA	NA	NA	NA
	IDLH	NA	100	NA	100
Nitrogen Dioxide (NO ₂)	TWA	NA	NA	3	NA
	STEL	NA	1	5	1
	Ceiling	5	NA	NA	5
	IDLH	NA	20	NA	20
Sulfur Dioxide (SO ₂)	TWA	5	2	2	2
	STEL	NA	5	5	5
	Ceiling	NA	NA	NA	NA
	IDLH	NA	100	NA	100

NA = Not applicable.

Note: All values are in parts per million (ppm) based on volume.

The standard/criteria for exposure to carbon monoxide is specified in Appendix B and References 8 and 9. Those standards are military unique and govern the determination of exposure hazards whether or not the exposure is transient or steady state.

2.1 The gases listed in Table C-1 are common to automotive type vehicles as well as for combat vehicle systems from which weapons may be fired. As indicated, the table includes values from more than one reference. The standards apply to the industrial workplace where exposures are usually of the steady state type (i.e., reasonably constant) in contrast to transient type exposures which vary as a function of time in most military scenarios. References 6, 10, and 26 have been used to develop Table C-1. These values were used as guidelines and the most stringent exposure criteria were adopted. The following are definitions of the column headings.

Exposure Type Definitions.

(1) Eight-hour time-weighted average (8-hr TWA). The TWA concentration is based upon a normal 8-hour workday and a 40-hour workweek.

$$TWA_c = [c_1t_1 + c_2t_2 + c_3t_3 + \dots + c_n t_n]/8$$

where:

- TWA_c = the total equivalent exposure for an 8-hour period.
 t = an individual exposure period (hours).
 c = the measured gas concentration (ppm) for the specific exposure time period.

The subscripts represent the individual time segments (1 through n) for each test segment (hours).

(2) STEL. A 15-minute TWA exposure which should not be exceeded at any time during a workday. Exposures up to the STEL should not be longer than 15 minutes and should not occur more than 4 times per day. There should be at least 60 minutes between successive exposures in this range.

(3) Ceiling. The concentration that should not be exceeded during any part of the working exposure time. If instantaneous monitoring is not feasible, then the ceiling shall be assessed as a 15-minute TWA.

(4) IDLH. Immediately Dangerous to Life and Health. This value is considered the concentration at which a worker should immediately vacate the exposure area, because serious and potentially irreversible health effects could result in less than 30 minutes. Only highly reliable respiratory protection equipment tailored to address each specific toxic gas should be used in environments with these concentrations.

2.2 Halon (FE 1301 - Bromotrifluoromethane $CBrF_3$)

2.2.1 FE 1301 is the fire suppressant agent selected by the Army as least toxic of the fire suppressant agents. This agent is mainly used in automatic fire extinguishing systems (AFES) integral with armored combat vehicle systems. Concentrations of 5 to 6 percent by volume are considered adequate to extinguish fires of most combustible materials. The agent is unstable at temperatures above 810 °K (1000 °F). At higher temperatures it decomposes predominantly into hydrogen fluoride and hydrogen bromide, amongst other products, which are highly toxic gases to humans. Unfortunately, FE 1301 has been identified as an ozone depleting chemical and according to an international treaty (Montreal Protocol) the Army must discontinue use of this chemical as a fire extinguishing agent.

2.2.2 Exposure time is critical in determining the degree of toxicity in the inhalation of gases. Fortunately, it would be unusual for humans to be exposed acutely (involving potentially lethal concentrations) to FE 1301 (and the other suppressants) because the hazards associated with fires generally override those associated with an extinguishing agent. Although one should avoid unnecessary exposure to FE 1301, all exposures should be limited to the following times for purposes of safety:

- 7 percent and below - 15 minutes
- 7 to 10 percent - 1 minute
- 10 to 15 percent - 30 seconds
- Above 15 percent - not permissible

Alternatively, TLV represents another guideline for maintaining safe exposure levels in the work place. The TLV for FE 1301 is 1,000 ppm as published by ACGIH¹⁰. The preceding table is from paragraph A-1-6.1 of Reference 27.

2.2.3 As indicated in Paragraph 2.2.1, above, FE 1301 is the least toxic fire suppressant agent of those currently in use. Although not used frequently, Halons 1211 and 2402 are also common in some manually operated extinguishers in scenarios other than the battlefield. The following are guidelines governing exposure to those suppressants.

a. Halon 1211, Limit exposure to this suppressant to the following times:

- up to 4 percent - 5 minutes
- 2 to 5 percent - 1 minute
- Above 5 percent - prevent exposure²⁸

b. Halon 2402- "Means shall be provided to prevent personnel from being exposed to Halon 2402 vapors in concentrations of greater than 0.05 percent (500 ppm) percent by volume for 10 minutes or 0.10 percent (1000 ppm) percent for 1 minute"²⁹.

2.3 Lead Aerosol (Particulate). The current criteria for exposure to lead are specified in Reference 22, and they fundamentally represent the civilian occupational standards. Reference 6 refers air contaminants of lead to Reference 22. The specification is quoted as follows:

a. 1910.1025(c).

(1) The employer shall assure that no employee is exposed to lead at concentrations greater than fifty micrograms per cubic meter of air averaged over an 8-hour period.

(2) If an employee is exposed to lead for more than 8 hours in any work day, the permissible exposure limit, as a TWA for that day, shall be reduced according to the following formula:

Maximum permissible limit (in micrograms/m³) = 400 divided by hours worked in the day.

b. The ACGIH¹⁰ and OSHA specify an 8-hour TWA of 0.05 mg/m³ for lead aerosol/dusts, while the NIOSH Recommended Exposure Limit (REL) for an 8-hour TWA is 0.100 mg/m³. NIOSH further recommends an IDLH value of 100 mg/m³ for particulate lead. The Biological Exposure Index (BEI) for lead is specified in Table C-2. The BEIs are reference values intended as guidelines for the evaluation of potential health hazards in the practice of industrial hygiene. BEIs represent the levels of the determinant that are most likely to be observed in specimens collected from a healthy worker who has been exposed to the chemical to the same extent as a worker with inhalation exposure to the TLV.

TABLE C-2. BIOLOGICAL EXPOSURE INDICES FOR LEAD

Parameter	Sampling Time	BEI
Lead in Blood	Not Critical	50 µg/100 mL
Lead in Urine	Not Critical	150 µg/g creatinine
Zinc Protoporphyrin in Blood	After 1 month exposure	250 µg/100 mL erythrocytes or 100µg/100 mL blood

c. The U.S. Army Center for Health Promotion and Preventive Medicine, Occupational and Environmental Medicine Division has developed permissible limits for intermittent lead exposures relating to firing ranges. These standards are specified in Table C-3.

TABLE C-3. LIMITS OF EXPOSURE FOR LEAD

Airborne Lead Concentrations mg/m ³	Firing 30 or More Days/Year hours/day	Firing Less Than 30 Days/Year hours/day
0.00 to 0.03	8.00	8.00
0.03 to 0.04	6.00	8.00
0.04 to 0.05	4.50	8.00
0.05 to 0.06	4.00	6.50
0.06 to 0.08	3.00	5.00
0.08 to 0.10	2.25	4.00
0.10 to 0.15	1.50	2.50
0.15 to 0.20	1.00	2.00
0.20 to 0.30	0.75	1.25
0.30 to 0.40	0.50	1.00
0.40 to 0.50	0.50	0.75
0.50 to 0.75	0.25	0.50
0.75 to 1.00	0.25	0.25
>1.0	0.00	0.00

2.4 Heptafluoropropane (FM-200).

2.4.1 FM-200 is the fire suppressant agent selected by the Army as the replacement to FE 1301 in occupied spaces. This agent is mainly used in automatic fire extinguishing systems (AFES) integral with armored combat vehicle systems. Concentrations of 5 to 7.8 percent by volume are considered adequate to extinguish fires of most combustible materials. At higher temperatures this chemical decomposes predominantly into hydrogen fluoride and carbonyl fluoride, amongst other products, which are highly toxic gases to humans.

2.4.2 Exposure time is critical in determining the degree of toxicity in the inhalation of gases. Fortunately, it would be unusual for humans to be exposed acutely (involving potentially lethal concentrations) to FM-200 (and the other extinguishants) because the hazards associated with fires generally override those associated with an extinguishing agent. Although one should avoid unnecessary exposure to FM-200, all exposures should be limited to the times in Table C-4 for purposes of safety.

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TABLE C-4. TIME FOR SAFE HUMAN EXPOSURE AT
STATED CONCENTRATIONS FOR FM-200

Heptafluoropropane (FM-200) Concentration		Human Exposure Time, min
Percent, v/v	ppm	
9.0	90,000	5.00
9.5	95,000	5.00
10.0	100,000	5.00
10.5	105,000	5.00
11.0	110,000	1.13
11.5	115,000	0.60
12.0	120,000	0.49

APPENDIX D. TEST INSTRUMENTATION TYPES/DETAILS

1. INTRODUCTION. This Appendix is prepared to provide the toxic gas and aerosol tester and/or test planner with a central depository for specifying test instrumentation and sampling requirements for making exposure measurements relating to the different types of gaseous compounds discussed in this document. Detailed information regarding laboratory instrumentation that may be required is not included in this appendix. Although some data governing instrumentation requirements are presented in the main body of this document, additional instrumentation specifications are presented here which may be of use to the planner, tester, and/or evaluator.

2. MEASUREMENT METHODS. There are several methods used to measure concentrations of gases, vapors, mists, dusts, etc. in the atmosphere. Some of these methods include:

- Continuous-emissions monitors.
- Hand-held toxic gas analyzers.
- Fourier transform infrared (FTIR) spectrometer.
- Sorbent tubes with laboratory analysis.
- Impinger trapping solution.
- Whole air sampling with laboratory analysis.
- Gravimetric-type collectors.

Each of these devices/methods will be discussed individually.

2.1 Continuous Emissions Monitors (CEMs). There are several different types of CEMs that quantitatively react to target gas concentrations by a variety of mechanisms. Some compounds can be detected by more than one type of instrument. Each instrument type may have advantages or disadvantages based on the specific test conditions or application. Instruments should be selected on a case by case basis by considering known or potential interferences in the test, available sampling volume, expected analyte concentration, as well as other factors that may not be listed. Several common types of CEMs are discussed below:

a. Spectrophotometric devices measure the amount of light energy absorbed in a gas sample. These devices can be divided into two subcategories of nondispersive spectrometers and gas correlation filters. The following gases can be measured by this technique: CO, CO₂, NO, NO₂, NH₃, SO₂, CH₄, as well as others that may not be listed.

(1) Non-dispersive spectrometers simultaneously pass broadband light through a sample stream from the atmosphere being measured and a reference cell containing the analyte gas of interest. The transmitted radiation in each beam is absorbed by a pair of detectors forming the arms of a Wheatstone bridge. The Wheatstone bridge is able to provide an output that is indicative of the concentration of the analyte in the sample stream.

(2) Gas filter correlation instruments typically pass broadband light through a sample and then divide the light into equal parts with a beam splitting device (half-silvered mirror or other device). The two light paths are passed through filters that transmit a narrow frequency band. The frequency bands are chosen such that the measuring filter passes light frequencies that are selectively absorbed by the analyte of interest, while the reference filter passes light frequencies that are not absorbed by the analyte. Each light path has a separate detector that is electronically correlated to provide an output that is proportional to the analyte concentration.

b. Paramagnetic devices use the magnetic properties of molecules to physically deflect a positioning device in a magnetic field. The amount of deflection is proportional to the concentration of the gas of interest. A restoring force is applied to the positioning device to bring it to the null deflection position. The restoring force is usually a current that is applied to a coil that surrounds the positioning device. The restoring force is generally converted to an output voltage. Atmospheric concentrations of oxygen can be measured by this technique.

c. Chemiluminescence uses chemical reactions that result in the production of light. For NO, the reaction involves $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 + h\nu$ (light). The amount of emitted light is proportional to the NO concentration in the sample stream. The interference problems for this analysis revolve around the conversion of nitrogen species to NO. Various converters can be used to convert NO_2 and NH_3 to NO. Bypassing the converter gives NO concentration, while a molybdenum converter gives combined NO and NO_2 (NO_x) concentration, and a stainless steel converter is used to get NO, NO_2 , and NH_3 . Using a combination of these converters and bypasses can accurately produce simultaneous NO, NO_2 , NO_x , and NH_3 results.

d. Pulsed fluorescence also uses the production of light; however, this process does not involve any chemical reactions. By definition, fluorescence implies that light is emitted after excitation by radiant sources of energy. In this case, $\text{SO}_2 + h\nu_1 \rightarrow \text{SO}_2^* \rightarrow \text{SO}_2 + h\nu_2$, where $h\nu_1$ is pulsed ultraviolet light, SO_2^* is an electronically excited molecule, and $h\nu_2$ is the emitted light. The amount of emitted light is proportional to the SO_2 concentration in the sample stream.

2.2 Hand-Held Gas Analyzers. Hand-held gas analyzers are convenient to use for mobile systems where it is not practical to use CEMs. These analyzers are also used for confined space monitoring, personnel monitoring, or other applications where space is limited and extractive sampling is impractical. Hand-held analyzers can be used to quantitatively analyze for CO, CO_2 , H_2S , SO_2 , H_2 , NO_2 , HCN, O_2 , and combustible gases, as well as other gases that may not be listed. These analyzers typically utilize the following techniques to measure gas concentrations:

a. Catalytic devices measure the heat produced by chemical reactions on catalytic surfaces or in granular catalytic beds.

b. Semiconductor sensors utilize an electrical-resistance change of the semiconductor material when the gas of interest is absorbed on its surface.

c. Electrochemical devices provide for an electrical phenomenon when the gas sample comes in contact with the chemical sensor.

2.3 Fourier Transform Infrared (FTIR) Spectroscopy. FTIR can be used to determine concentrations of several gases simultaneously provided that the molecule of interest has a dipole moment (of inertia). Homonuclear diatomic molecules such as N_2 , O_2 , and Cl_2 do not have a dipole moment and can not be detected by FTIR. FTIR operates on the principal of Beer's Law which shows a logarithmic relationship between absorbed light and gas concentration.

$$\text{Absorbance} = \log (I_0/I) = \epsilon bc$$

where:

I_0 is the intensity of the incident radiation.

I is the intensity after sample absorption.

ϵ is the extinction coefficient (fundamental property of each gas).

b is the absorption path length,

c is concentration. In practice, absorbance is measured at various wavelengths to get a plot of absorbance versus frequency. The pathlength is varied to change instrument sensitivity. Typical path lengths include 10 cm, 1, 3, and 10 meter. These path lengths can produce a detection range that varies from 50 ppb to 5 percent depending on the chemical properties of particular gas. Measuring absorptions at several gas concentrations forms a calibration curve. Sample spectra are compared to calibration spectra in order to determine gas concentrations. Sometimes gases can be detected by this technique, but spectral interferences elevate detection limits beyond practical use. NO_2 provides a good example, because its prime absorption overlaps with water vapor. Other gases, such as H_2S , are very poor absorbers of infrared radiation, and therefore, can not be analyzed via this technique. Each particular scenario should be evaluated to determine if FTIR is a viable technique. FTIR has been successfully used to measure CO , CO_2 , HF , HCl , HBr , COF_2 , HCN , SF_6 , NH_3 , CH_4 , CF_3Br , C_3F_7H , C_3F_8 , $C_3F_6H_2$, H_2O , and COS .

2.4 Sorbent Tubes. Air is drawn through a tube that contains media that selectively adsorbs particular analytes. Sorbent tubes generally adsorb gaseous material and they are sometimes used in conjunction with filters, which trap particulate matter. The sorbent media varies depending on the analytes of interest. There are several manufactures and suppliers of sorbent tubes and the suppliers of these materials generally provide guides to aide in the selection of the correct media. Sorbent tubes are processed in the laboratory to extract or desorb the analyte of interest for quantification. Based on the amount of analyte determined by the laboratory analysis and the volume of air drawn through the sorbent tube, one can calculate the amount of analyte per unit volume of air. One must be careful to follow all instructions for media preparation, holding times, volume limitations, concentration limitations, and flow rate limitations that are prescribed by the method being used for collection and analysis.

2.5 Impinger Trapping Solutions. Trapping solutions can be used to extract gas vapors from air and keep the compound in solution for later laboratory analysis. Generally, a filter will be placed at the front of an impinger sampling train, so that any analyte that may be adsorbed on particulate matter can be captured on this media. The particulate and vapor phase concentrations can then be combined for a total dose calculation. Acid gases such as HF and HCl, as well as HCN can be accurately analyzed by this technique. For example, hydrogen cyanide is collected via a polyvinyl chloride particulate filter and an impinger with 0.1 N potassium hydroxide (KOH). The filter and impinger are analyzed separately for cyanide by ion chromatography. The filter results correlate to particulate cyanide and the impinger results correspond to gaseous hydrogen cyanide concentration. This procedure is a modified version of Reference 11 with specific details provided in Reference 12.

2.6 Whole Air Sampling With Laboratory Analysis. Whole air samples can be drawn from field locations and brought back to the laboratory for later analysis. These samples can be placed in evacuated canisters or bags. Canisters must be selected to specifically meet the sampling and analysis requirements for each particular analyte to be measured. Evacuated canisters can gather air in an active or passive mode. During passive sampling a flow control orifice is opened and air is allowed to enter the canister at a controlled rate. In active sampling, air is directly pumped into the canister. Bag samples are collected in special air tight boxes where an evacuated bag is placed in the box and air is extracted from the box. Tubing is run from a sampling location to a bulkhead fitting (box pass through) and connected to the bag input valve. When a vacuum is created in the box, air flows from the sampling location into the bag. The type of laboratory analysis depends on the analyte of interest.

2.7 Gravimetric-Type Collectors. These devices collect dust and particulates in a filter medium by drawing the contaminated air with a pump of known flow rate. The collected matter is then weighed which provides one with a known amount of particulate contamination (mg/m^3). Collection devices can be used to segregate the size of particulate matter. An eight stage cascade impactor can be used to speciate the sizes of particulate into eight individual stages which can be measured and analyzed individually. Particulate matter that is 10 microns or less is considered inhalable, while 2.5 microns or less is respirable. The size of the particulate will ultimately affect the body's response to inhalation.

3. INSTRUMENTATION SELECTION. Principal considerations involved in selection of test instrumentation are: principle of operation, accuracy, measurement range, sensitivity, response time, reliability, portability, specificity, repeatability, ruggedness, size, ease of calibration, complexity of human interface, recording capability, sensitivity to shock and vibration, and cost. Many of these considerations are intertwined with one another in that if the accuracy, sensitivity, response time and reliability are acceptable, the probability is high that, with the exception of cost and insensitivity to shock and vibration, the other considerations will also be acceptable. The following tables represent guidelines that can be used for instrumentation selection.

TABLE D-1. AUTOMOTIVE TESTING INSTRUMENTATION GUIDELINES

Analyte	Maximum Permissible Error	Permissible Detection Limit
Carbon Monoxide (CO)	5% of Actual Value	< 5 ppm
Carbon Dioxide (CO ₂)	5% of Actual Value	< 500 ppm
Sulfur Dioxide (SO ₂)	5% of Actual Value	< 0.3 ppm
Nitrogen Dioxide (NO ₂)	5% of Actual Value	< 0.3 ppm
Hydrocarbons (HC)	5% of Actual Value	< 5 ppm
Temperature (internal and external)	± 1 °C	NA
Relative Humidity (internal and external)	$\pm 0.15\%$	3%
Vehicle Speed ^a	± 3 km/hr	NA
Wind Speed ^b	± 0.25 m/sec	NA

^aVehicle speedometer value acceptable.

^bFor static automotive tests only.

TABLE D-2. WEAPONS SYSTEMS TESTING INSTRUMENTATION REQUIREMENTS

Instrument	Response Time	Permissible Measurement Error	Minimum Measurement Frequency, Hz
Ammonia (NH ₃)	<10 sec to 90% FS	<2% at FS	1.00
Carbon Monoxide (CO)	<10 sec to 90% FS	<2% at FS	1.00
Carbon Dioxide (CO ₂)	<10 sec to 90% FS	<2% at FS	1.00
Sulfur Dioxide (SO ₂)	<10 sec to 90% FS	<2% at FS	1.00
Nitrogen Oxides (NO _x)	<10 sec to 90% FS	<2% at FS	1.00
Temperature (internal and external)	< 30 sec	1 °C	0.01
Relative Humidity (internal and external)	< 30 sec	3 %	0.01
Wind Speed and Direction	< 30 sec	0.25 m/sec	0.01

FS = Full scale.

Additional Specifications for Instruments:

Zero Drift per day: <1% at FS.

Sensitivity Drift per day: <0.3% at FS.

Typical temperature effect per °K: <0.1% at FS.

Ambient pressure influence on concentration: 0.1% of measured value per millibar (mbar) pressure difference.

TABLE D-3. INSTRUMENTATION SPECIFICATIONS ENVIRONMENTAL/
METEOROLOGICAL MEASUREMENTS

Measurement	Minimum Response Time, sec	Maximum Error	Measurement Frequency, Hz
Temperature	<30	1 °C	1
Relative Humidity	<30	3%	1
Barometric Pressure	<30	1 mm-Hg	1
Wind Speed and Direction	<30	0.25 m/sec	1

APPENDIX E. SAMPLE FIRING SCENARIOS

1. INTRODUCTION. This Appendix is intended to provide the toxic gas and aerosol tester with sample test firing scenarios in the event the DTP excludes such details. Often, such details are lacking because vehicle tactical operations and analyses are not issues for the developer to resolve and the user (TRADOC) has not finalized plans for the training of crews at the phase of the system development when toxic gas and aerosol testing has been scheduled. Sometimes a standard battle scenario does exist from which the tester is able to develop appropriate test scenarios.

In the absence of a realistic test scenario, the tester must provide one that balances system specification constraints with conduction of tests, which are both technically correct and economically sensible. Because the health and safety of interfacing crews are at stake, the tester must be capable of identifying firing rates and crew positions that are critical from a toxic gas and aerosol exposure viewpoint. Ordinarily, experience provides the tester with this knowledge. The test program should not become overly stringent and result in needless testing or testing which departs from realism such as exceeding weapons design specifications (unusually rapid firing rates) or firing weapons from vehicles with hatches closed and no active ventilation.

The following paragraphs provide guidance as to scenarios used for systems already fielded.

2. BRADLEY FIGHTING VEHICLE (BFV) SYSTEM TEST SCENARIO. TRADOC Scenario Events 12 and 15: The TRADOC Scenario depicts the BFV as part of a mechanized infantry battalion conducting an active 24-hour defense. Events 12 and 15 represent the most intense fighting episodes during the 24-hour period. Events 13 and 14 are nonfiring events covering a total of 22 minutes. To assess the worst case toxic gas and aerosol exposure, Events 12 and 15 are conducted sequentially, thus omitting the 22 minute pause between the critical firing episodic events. Table E-1 summarizes the BFV test scenario.

TABLE E-1. TRADOC FIRING SCENARIO

Event 12				Event 15			
Time, min	25 mm	7.62 mm	Mode	Time, min	25 mm	7.62 mm	Mode
0.0	10	-	SS	26.0	10	-	SS
2.0	10	-	SS	27.0	10	-	SS
4.0	10	-	SS	28.0	10	-	SS
6.0	10	-	SS	29.0	10	-	SS
8.0	10	-	SS	30.0	10	-	SS
10.0	10	-	SS	31.0	10	-	SS
11.0	10	-	SS	32.0	10	-	SS
12.0	10	-	SS	33.0	10	-	SS
13.0	-	21	B	34.0	10	-	SS
14.0	-	21	B	35.0	10	-	SS
15.0	-	21	B	36.0	10	-	SS
17.0	-	21	B	36.5	10	-	SS
19.0	-	42	B	37.0	10	-	SS
20.0	-	21	B	38.0	10	-	SS
21.0	-	43	B	39.0	10	-	SS
21.5	5	-	SS	40.0	5	-	SS
22.0	5	-	B	40.5	5	-	B
22.5	5	-	SS	41.0	5	-	SS
23.0	5	-	B	41.5	5	-	B
23.5	5	-	SS	42.0	5	-	SS
24.0	5	-	B	42.5	5	-	B
25.0	5	-	B	43.0	5	-	SS
				43.5	5	-	B
				44.0	5	-	SS
				44.5	10	-	B
				45.0	-	55	B
				46.0	-	55	B

B = Burst (low rate).
SS = Single shot.

3 TANK MAIN GUN TRAINING SCENARIO. The following training scenario was provided by the U.S. Army Armor Center at Fort Knox, Kentucky (ATSB-WP-GD) during April 1986 for purposes of toxic gas and aerosol testing.

Segment	Test Procedure
1	Fire three main gun rounds within 1 minute.
2	Pause for 3 minutes.
3	Fire two rounds within 1 minute.
4	Pause 4 minutes.
Option: Fire 100 rounds from the coax machine gun at the start of the 4-minute pause (25-round bursts at 15 sec intervals).	
5 and 6	Repeat 1 and 2 segments, above.
7	Repeat segment 1.
8	Pause 2 minutes.

Total test time: 16 minutes.

Rounds fired: 11 main gun; 100 coax.

Note: Training round ammunition usually provides for greater toxic gas and aerosol exposure than does conventional battlefield ammunition.

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